(a) (b)

Figure 3-8. Split Barrel Sampler: (a) Open sampler with soil sample and cutting shoe; (b) Sample jar, split-spoon, shelby tube, and storage box for transport of jar samples.

(a) (b)

Figure 3-9. Split Barrel Sampler. (a) Stainless steel and brass retainer rings (b) Sample catchers.

In U.S. practice, it is normal to omit the inside liner in the split-spoon barrel. The resistance of the sampler to driving is altered depending upon whether or not a liner is used (Skempton, 1986; Kulhawy & Mayne, 1990). Therefore, in the case that a liner is used, then the boring logs used be clearly noted to reflect this variation from standard U.S. procedures, as the reported numbers in driving may affect the engineering analysis.

Thin Wall Sampler

The thin-wall tube (Shelby) sampler is commonly used to obtain relatively undisturbed samples of cohesive soils for strength and consolidation testing. The sampler commonly used (Figures 3-10) has a 76 mm (3.071 in) outside diameter and a 73 mm (2.875 in) inside diameter, resulting in an area ratio of 9 percent. Thin wall samplers vary in outside diameter between 51 mm (2.0 in) and 76 mm (3.0 in) and typically come in lengths from 700 mm (27.56 in) to 900 mm (35.43 in), as shown in Figure 3-11. Larger diameter sampler tubes are used where higher quality samples are required and sampling disturbance must be reduced. The test method for thin-walled tube sampling is described in AASHTO T 207 and ASTM D 1587.

The thin-walled tubes are manufactured using carbon steel, galvanized-coated carbon steel, stainless steel, and brass. The carbon steel tubes are often the lowest cost tubes but are unsuitable if the samples are to be stored in the tubes for more than a few days or if the inside of the tubes become rusty, significantly increasing the friction between the tube and the soil sample. In stiff soils, galvanized carbon steel tubes are preferred since carbon steel is stronger, less expensive, and galvanizing provides additional resistance to corrosion. For offshore bridge borings, salt-water conditions, or long storage times, stainless steel tubes are preferred. The thin-walled tube is manufactured with a beveled front edge for cutting a reduced-diameter sample [commonly 72 mm (2.835 in) inside diameter] to reduce friction. The thin-wall tubes can be pushed with a fixed head or piston head, as described later.

The thin-wall tube sampler should not be pushed more than the total length up to the connecting cap less 75 mm (3 in). The remaining 75 mm (3 in) of tube length is provided to accommodate the slough that accumulates to a greater or lesser extent at the bottom of the boring. The sample length is approximately 600 mm (24 in). Where low density soils or collapsible materials are being sampled, a reduced push of 300 mm (12 in) to 450 mm (18 in) may be appropriate to prevent the disturbance of the sample. The thin-walled tube sampler should be pushed slowly with a single, continuous motion using the drill rig's hydraulic system. The hydraulic pressure required to advance the thin-walled tube sampler should be noted and recorded on the log. The sampler head contains a check valve that allows water to pass through the sampling head into the drill rods. This check valve must be clear of mud and sand and should be checked prior to each sampling attempt. After the push is completed, the driller should wait at least ten minutes to allow the sample to swell slightly within the tube, then rotate the drill rod string through two complete revolutions to shear off the sample, and then slowly and carefully bring the sample to the surface. In stiff soils it is often unnecessary to rotate the sampler.

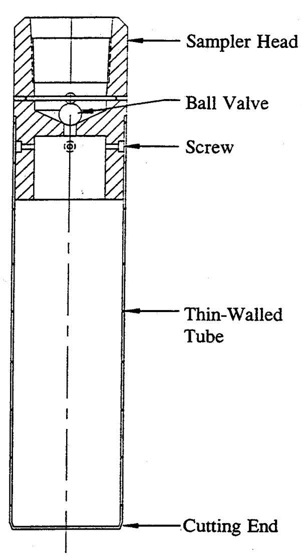


Figure 3-10. Schematic of Thin-Walled Shelby Tube (After ASTM D 4700).

Figure 3-11. Selected Sizes and Types of Thin-Walled Shelby Tubes.

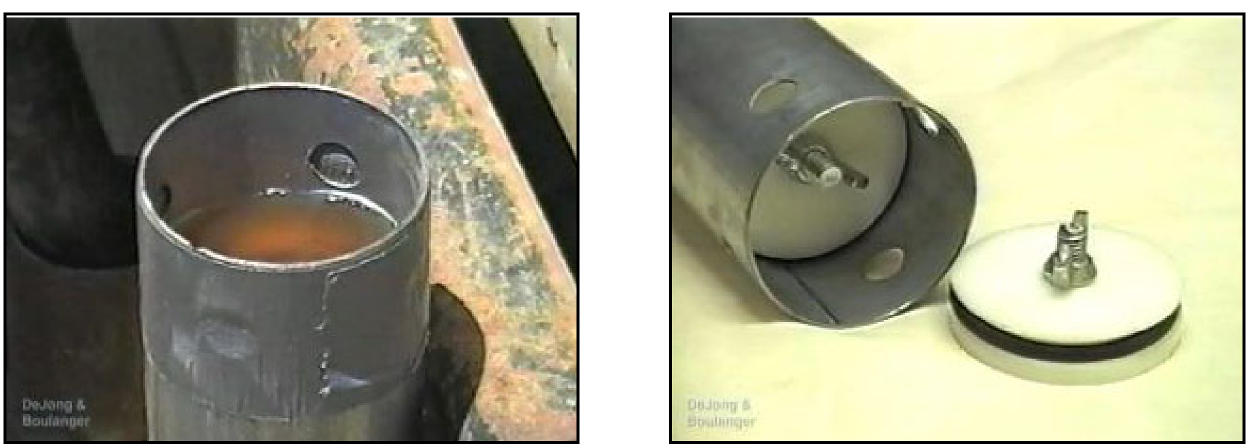
After taking a thin-walled tube sample, slough or cuttings from the upper end of the tube should be removed using a cleanout tool. The length of sample recovered should be measured and the soil classified for the log. About 25-mm of material at the bottom end of the tube should be removed and the cuttings placed in a properly labeled storage jar. Both ends of the tube should then be sealed with at least a 25 mm (1 in) thick layer of microcrystalline (nonshrinking) wax after placing a plastic disk to protect the ends of the sample (Figure 3-12a). The remaining void above the top of the sample should be filled with moist sand. Plastic end caps should then be placed over both ends of the tube and electrician's tape placed over the joint between the collar of the cap and the tube and over the screw holes. The capped ends of the tubes are then dipped in molten wax. Alternatively, O-ring packers can be inserted into the sample ends and then sealed (Figure 3-12b). This may be preferable as it is cleaner and more rapid. In both cases, the sample must be sealed to ensure proper preservation of the sample. Samples must be stored upright in a protected environment to prevent freezing, desiccation, and alteration of the moisture content (ASTM D 4220).

In some areas of the country, the thin-walled tube samples are field extruded, rather than transported to the laboratory in the tube. This practice is not recommended due to the uncontrolled conditions typical of field operations, and must not be used if the driller does not have established procedures and equipment for preservation and transportation of the extruded samples. Rather, the tube sample should be transported following ASTM D 4220 guidelines to the laboratory and then carefully extruded following a standardized procedure.

The following information should be written on the top half of the tube and on the top end cap: project number, boring number, sample number, and depth interval. The field supervisor should also write on the tube the project name and the date the sample was taken. Near the upper end of the tube, the word "top" and an arrow pointing toward the top of the sample should be included. Putting sample information on both the tube and the end cap facilitates retrieval of tubes from laboratory storage and helps prevent mix-ups in the laboratory when several tubes may have their end caps removed at the same time.

Piston Sampler

The piston sampler (Figure 3-13) is basically a thin-wall tube sampler with a piston, rod, and a modified sampler head. This sampler, also known as an Osterberg or Hvorslev sampler, is particularly useful for sampling soft soils where sample recovery is often difficult although it can also be used in stiff soils.



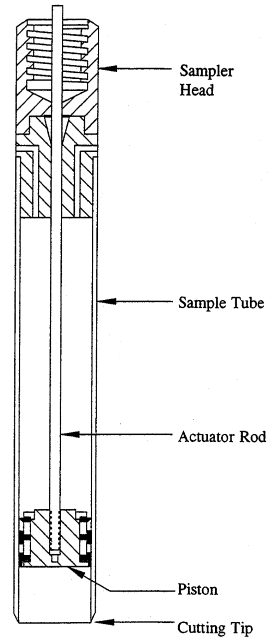
(a) (b)

Figure 3-12. Shelby Tube Sealing Methods. (a) Microcrystalline wax (b) O-ring packer.

The sampler, with its piston located at the base of the sampling tube, is lowered into the borehole. When the sampler reaches the bottom of the hole, the piston rod is held fixed relative to the ground surface and the thin-wall tube is pushed into the soil slowly by hydraulic pressure or mechanical jacking. The sampler is never driven. Upon completion of sampling, the sampler is removed from the borehole and the vacuum between the piston and the top of the sample is broken. The piston head and the piston are then removed from the tube and jar samples are taken from the top and bottom of the sample for identification purposes. The tube is then labeled and sealed in the same way as a Shelby tube described in the previous section.

The quality of the samples obtained is excellent and the probability of obtaining a satisfactory sample is high. One of the major advantages is that the fixed piston helps prevent the entrance of excess soil at the beginning of sampling, thereby precluding recovery ratios greater than 100 percent. It also helps the soil enter the sampler at a constant rate throughout the sampling push. Thus, the opportunity for 100 percent recovery is increased. The head used on this sampler also acts creates a better vacuum which helps retain the sample better than the ball valve in thin-walled tube (Shelby) samplers.

(a)



(b)

Figure 3-13. Piston Sampler: (a) Picture with thin-walled tube cut-out to show piston; (b) Schematic (After ASTM D 4700).

Pitcher Tube Sampler

The pitcher tube sampler is used in stiff to hard clays and soft rocks, and is well adapted to sampling deposits consisting of alternately hard and soft layers. This sampler is pictured in Figure 3-14 and the primary components shown in Figure 3-15a. These include an outer rotating core barrel with a bit and an inner stationary, spring-loaded, thin-wall sampling tube that leads or trails the outer barrel drilling bit, depending on the hardness of the material being penetrated.

Figure 3-14. Pitcher Tube Sampler.

When the drill hole has been cleaned, the sampler is lowered to the bottom of the hole (Figure 3-15a). When the sampler reaches the bottom of the hole, the inner tube meets resistance first and the outer barrel slides past the tube until the spring at the top of the tube contacts the top of the outer barrel. At the same time, the sliding valve closes so that the drilling fluid is forced to flow downward in the annular space between the tube and the outer core barrel and then upward between the sampler and the wall of the hole. If the soil to be penetrated is soft, the spring will compress slightly (Figure 3-15b) and the cutting edge of the tube will be forced into the soil as downward pressure is applied. This causes the cutting edge to lead the bit of the outer core barrel. If the material is hard, the spring compresses a greater amount and the outer barrel passes the tube so that the bit leads the cutting edge of the tube (Figure 3-15c). The amount by which the tube or barrel leads is controlled by the hardness of the material being penetrated. The tube may lead the barrel by as much as 150 mm (6 in) and the barrel may lead the tube by as much as 12 mm (0.5 in).

Sampling is accomplished by rotating the outer barrel at 100 to 200 revolutions per minute (rpm) while exerting downward pressure. In soft materials sampling is essentially the same as with a thin-wall sampler and the bit serves merely to remove the material from around the tube. In hard materials the outer barrel cuts a core, which is shaved to the inside diameter of the sample tube by the cutting edge and enters the tube as the sampler penetrates. In either case, the tube protects the sample from the erosive action of the drilling fluid at the base of the sampler. The filled sampling tube is then removed from the sampler and is marked, preserved, and transported in the same manner described above for thin-walled tubes.

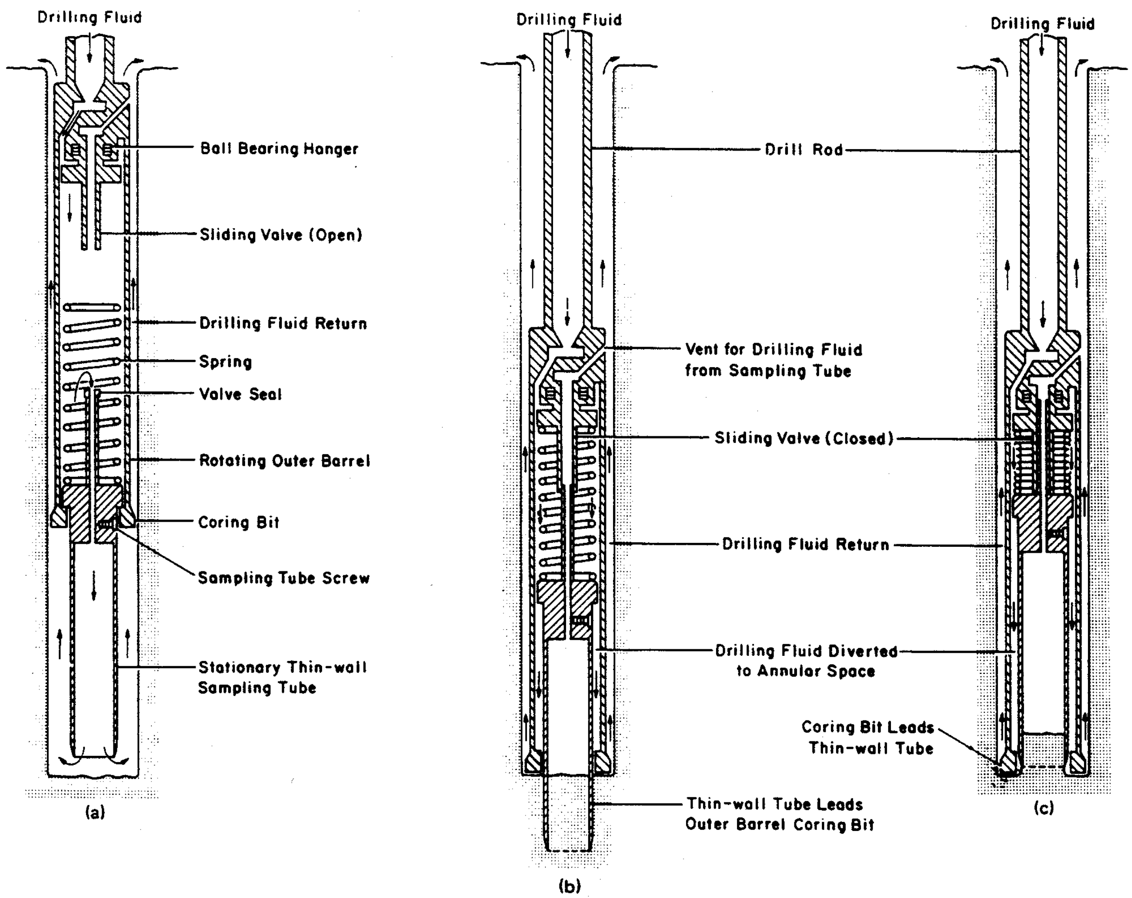


Figure 3-15. Pitcher Sampler. (a) Sampler Being Lowered into Drill Hole; (b) Sampler During Sampling of Soft Soils; (c) Sampler During Sampling of Stiff or Dense Soils (Courtesy of Mobile Drilling, Inc.).

Denison Sampler

A Denison sampler is similar to a pitcher sampler except that the projection of the sampler tube ahead of the outer rotating barrel is manually adjusted before commencement of sampling operations, rather than spring-controlled during sampler penetration. The basic components of the sampler (Figure 3-16) are an outer rotating core barrel with a bit, an inner stationary sample barrel with a cutting shoe, inner and outer barrel heads, an inner barrel liner, and an optional basket-type core retainer. The coring bit may either be a carbide insert bit or a hardened steel sawtooth bit. The shoe of the inner barrel has a sharp cutting edge. The cutting edge may be made to lead the bit by 12 mm (0.5 in) to 75 mm (3 in) through the use of coring bits of different lengths. The longest lead is used in soft and loose soils because the shoe can easily penetrate these materials and the longer penetration is required to provide the soil core with maximum protection against erosion by the drilling fluid used in the coring. The minimum lead is used in hard materials or soils containing gravel.

The Denison sampler is used primarily in stiff to hard cohesive soils and in sands, which are not easily sampled with thin-wall samplers owing to the large jacking force required for penetration. Samples of clean sands may be recovered by using driller's mud, a vacuum valve, and a basket catch. The sampler is also suitable for sampling soft clays and silts.

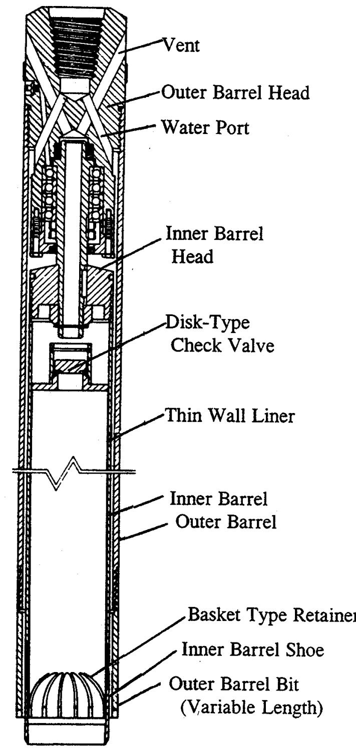


Figure 3-16. Denison Double-Tube Core Barrel Soil Sampler (Courtesy of Sprague & Henwood, Inc.)

Modified California Sampler

The Modified California sampler is a large lined tube sampler used in the Midwest and West, but uncommon in the East and South U.S.A. The sampler is thick-walled (area ratio of 77 percent) with an outside diameter of 64 mm (2.5 in) and an inside diameter of 51 mm (2 in). It has a cutting shoe similar to the split-barrel sampler, but with an inside diameter of generally 49 mm (1.93 in). Four 102-mm (4.0-in) long brass liners with inside diameters of 49 mm (1.93 in) are used to contain the sample. In the West, the Modified California sampler is driven with standard penetration energy. The unadjusted blow count is recorded on the boring log. In the Midwest the sampler is generally pushed hydraulically. When pushed, the hydraulic pressure required to advance the Modified California sampler should be noted and recorded on the log. The driving resistance obtained using a Modified California sampler is not equal to the standard penetration test resistance and must be adjusted if comparisons are necessary.

Continuous Soil Samplers

Several types of continuous soil samplers have been developed. The conventional continuous sampler consists of a 1.5 m (5 ft) long thick-walled tube which obtains "continuous" samples of soil as hollow-stem augers are advanced into soil formations. These systems use bearings or fixed hexagonal rods to restrain or reduce rotation of the continuous sampler as the hollow-stem augers are advanced and the tube is pushed into undisturbed soil below the augers. Recently, continuous hydraulic push samplers have been developed that are quick & economical (e.g., Geoprobe, Powerprobe). These samplers have inside diameters ranging from 15 mm (0.6 in) to 38.1 mm (1.5 in). A steel mandrel is pushed into the ground at a steady rate and the soil is recovered within disposable plastic liners. These devices typically are stand alone and do not require any drilling. If hard layers are encountered, a percussive vibrating procedure is used for penetration.

The continuous samples are generally disturbed and therefore are only appropriate for visual observation, index tests, and classification-type laboratory tests (moisture, density). Continuous samplers have been shown to work well in most clayey soils and in soils with thin sand layers. Less success is typically observed when sampling cohesionless soil below the groundwater level, soft soils, or samples that swell following sampling although modifications are available to increase sample recovery. Information is limited regarding the suitability of the continuous samples for strength and consolidation tests and therefore must be used with caution.

Other Soil Samplers

A variety of special samplers are available to obtain samples of soil and soft rocks. These methods include the retractable plug, Sherbrooke, and Laval samplers. These sampling methods are used in difficult soils where the more routine methods do not recover samples.

Bulk Samples

Bulk samples are suitable for soil classification, index testing, R-value, compaction, California Bearing Ratio (CBR), and tests used to quantify the properties of compacted geomaterials. The bulk samples may be obtained using hand tools without any precautions to minimize sample disturbance. The sample may be taken from the base or walls of a test pit or a trench, from drill cuttings, from a hole dug with a shovel and other hand tools, by backhoe, or from a stockpile. The sample should be put into a container that will retain all of the particle sizes. For large samples, plastic or metal buckets or metal barrels are used; for smaller samples, heavy plastic bags that can be sealed to maintain the water content of the samples are used.

Usually, the bulk sample provides representative materials that will serve as borrow for controlled fill in construction. Laboratory testing for soil properties will then rely on compacted specimens. If the material is relatively homogeneous, then bulk samples may be taken equally well by hand or by machine. However, in stratified materials, hand excavation may be required. In the sampling of such materials it is necessary to consider the manner in which the material will be excavated for construction. If it is likely that the material will be removed layer by layer through the use of scrapers, samples of each individual material will be required and hand excavation from base or wall of the pit may be a necessity to prevent unwanted mixing of the soils. If, on the other hand, the material is to be excavated from a vertical face, then the sampling must be done in a manner that will produce a mixture having the same relative amounts of each layer as will be obtained during the borrow area excavation. This can usually be accomplished by hand-excavating a shallow trench down the walls of the test pit within the depth range of the materials to be mixed.

Block Samples

For projects where the determination of the undisturbed properties is very critical, and where the soil layers of interest are accessible, undisturbed block samples can be of great value. Of all the undisturbed testing methods discussed in this manual, properly-obtained block samples produce samples with the least amount of disturbance. Such samples can be obtained from the hillsides, cuts, test pits, tunnel walls and other exposed sidewalls. Undisturbed block sampling is limited to cohesive soils and rocks. The procedures used for obtaining undisturbed samples vary from cutting large blocks of soil using a combination of shovels, hand tools and wire saws, to using small knives and spatulas to obtain small blocks.

In addition, special down-hole block sampling methods have been developed to better obtain samples in their in-situ condition. For cohesive soils, the Sherbrooke sampler has been developed and is able to obtain samples 250 mm (9.85 in) diameter and 350 mm (13.78 in) height (Lefebvre and Poulin 1979). In-situ freezing methods for saturated granular soils and resin impregnation methods have been implemented to "lock" the soil in the in-situ condition prior to sampling. When implemented, these methods have been shown to produce high quality undisturbed samples. However, the methods are rather involved and time consuming and therefore have not seen widespread use in practice.

Once samples are obtained and transported to the laboratory in suitable containers, they are trimmed to appropriate size and shape for testing. Block samples should be wrapped with a household plastic membrane and heavy duty foil and stored in block form and only trimmed shortly before testing. Every sample must be identified with the following information: project number, boring or exploration pit number, sample number, sample depth, and orientation.

3.1.4 Sampling Interval and Appropriate Type of Sampler

In general, SPT samples are taken in both granular and cohesive soils, and thin-walled tube samples are taken in cohesive soils. The sampling interval will vary between individual projects and between regions. A common practice is to obtain split barrel samples at 0.75 m (2.5 ft) intervals in the upper 3 m (10 ft) and at 1.5 m (5 ft) intervals below 3 m (10 ft). In some instances, a greater sample interval, often 3 m (10 ft), is allowed below depths of 30 m (100 ft). In other cases, continuous samples may be required for some portion of the boring.

In cohesive soils, at least one undisturbed soil sample should be obtained from each different stratum encountered. If a uniform cohesive soil deposit extends for a considerable depth, additional undisturbed samples are commonly obtained at 3 m (10 ft) to 6 m (10 ft) intervals. Where borings are widely spaced, it may be appropriate to obtain undisturbed samples in each boring; however, for closely spaced borings, or in deposits which are generally uniform in lateral extent, undisturbed samples are commonly obtained only in selected borings. In erratic geologic formations or thin clay layers it is sometimes necessary to drill a separate boring adjacent to a previously completed boring to obtain an undisturbed sample from a specific depth which may have been missed in the first boring.

3.1.5 Sample Recovery

Occasionally, sampling is attempted and little or no material is recovered. In cases where a split barrel, or an other disturbed-type sample is to be obtained, it is appropriate to make a second attempt to recover the soil sample immediately following the first failed attempt. In such instances, the sampling device is often modified to include a retainer basket, a hinged trap valve, or other measures to help retain the material within the sampler.

In cases where an undisturbed sample is desired, the field supervisor should direct the driller to drill to the bottom of the attempted sampling interval and repeat the sampling attempt. The method of sampling should be reviewed, and the sampling equipment should be checked to understand why no sample was recovered (such as a plugged ball valve). It may be appropriate to change the sampling method and/or the sampling equipment, such as waiting a longer period of time before extracting the sampler, extracting the sampler more slowly and with greater care, etc. This process should be repeated or a second boring may be advanced to obtain a sample at the same depth.

3.1.6 Sample Identification

Every sample which is attempted, whether recovered or not, should be assigned a unique number composed of designators for the project number or name, boring number, sequential sample attempt number, and sample depth. Where tube samples are obtained, any disturbed tubes should be clearly marked with the sample identification number and the top and bottom of the sample labeled.

3.1.7 Relative Strength Tests

In addition to the visual observations of soil consistency, a pocket (hand) penetrometer can be used to estimate the strength of soil samples. The hand penetrometer estimates the unconfined strength and is suitable for firm to very stiff clay soils. A larger foot/adaptor is needed to test softer soils. It should be emphasized that this test does not produce absolute values; rather it should be used as a guide in estimating the relative strength of soils. **Values obtained with a hand penetrometer should not be used in design**. Instead, when the strength of soils (and other engineering properties) is required, in-situ tests and/or a series of laboratory tests (as described in Chapter 7) on undistrubed samples should be performed.

Another useful test device is a torvane, which is a small diameter vane shear testing device that provides an estimate of the shear strength of cohesive soils. Variable diameter vanes are available for use in very soft to very stiff cohesive soils. Again, this field test yields values that can be used for comparison purposes only, and **the torvane results should not be used in any geotechnical engineering analysis or design**.

Testing with a penetrometer or torvane should always be done in natural soils as near as possible to the center of the top or bottom end of the sample. Testing on the sides of extruded samples is not acceptable. ***Strength values obtained from pocket penetrometer or torvane should not be used for design purposes.***

3.1.8 Care and Preservation of Undisturbed Soil Samples

Each step in sampling, extruding, storing and testing introduces varying degrees of disturbance to the sample. Proper sampling, handling, and storage methods are essential to minimize disturbances. The geotechnical engineer must be cognizant of disturbance introduced during the various steps in sampling through testing. The field supervisors should be sensitized about disturbance and the consequences. A detailed discussion of sample preservation and transportation is presented in ASTM D 4220 along with a recommended transportation container design.

When tube samples are to be obtained, each tube should be examined to assure that it is not bent, that the cutting edges are not damaged, and that the interior of the tubes are not corroded. If the tube walls are corroded or irregular, or if samples are stored in tubes for long periods of time, the force required to extract the samples sometimes may exceed the shear strength of the sample causing increased sample disturbance.

All samples should be protected from extreme temperatures. Samples should be kept out of direct sunlight and should be covered with wet burlap or other material in hot weather. In winter months, special precautions should be taken to prevent samples from freezing during handling, shipping and storage. As much as is practical, the thin-walled tubes should be kept vertical, with the top of the sample oriented in the up position. If available, the thin-walled tubes should be kept in a carrier with an individual slot for each tube. Padding should be placed below and between the tubes to cushion the tubes and to prevent them from striking one another. The entire carrier should be secured with rope or cable to the body of the transporting vehicle so that the entire case will not tilt or tip over while the vehicle is in motion.

Soil sample extrusion from tubes in the field is an undesired practice and often results in sample swelling and an unnecessary high degree of disturbance. The stress relief undoubtably allows the specimens to soften and expand. The samples are also more susceptible to handling disturbances during transport to the laboratory. High-quality specimens are best obtained by soil extraction from tubes in the laboratory just prior to consolidation, triaxial, direct shear, permeability, and resonant column testing. However, to save money, some organizations extrude samples in the field in order to re-use the tubes and these samples are often wrapped in aluminum foil. Depending on the pH of the soil, the aluminum foil may react with the surface of the soil and develop a thin layer of discolored soil, thus making visual identification difficult and confusing. It may also result in changes in the moisture distribution across the sample. Even though plastic sheeting is also susceptible to reacting with the soil contacted, past observation shows that plastic has less effect than foil. Thus it is recommended that extruded soil samples which are to be preserved be wrapped in plastic sheeting and then wrapped with foil. However, if possible, samples should not be extracted from tubes in the field in order to minimize swelling, disturbance, transport, and handling issues.

Storage of undisturbed samples (in or out of tubes) for long periods of time under any condition is not recommended. Storage exceeding one month may substantially alter soil strength & compressibility as measured by lab tests.

3.2 EXPLORATION OF ROCK

The methods used for exploration and investigation of rock include:

- Drilling
- Exploration pits (test pits)
- Geologic mapping
- Geophysical methods

Core drilling which is used to obtain intact samples of rock for testing purposes and for assessing rock quality and structure, is the primary investigative method. Test pits, non-core drilling, and geophysical methods are often used to identify the top of rock.

Geophysical methods such as seismic refraction and ground penetrating radar (GPR) may be used to obtain the depth to rock. Finally, geologic mapping of rock exposures or outcrops provides a means for assessing the composition and discontinuities of rock strata on a large scale which may be valuable for many engineering applications particularly rock slope design. This section contains a discussion of drilling and geologic mapping. Some geophysical methods are discussed in section 5.7.

3.2.1 Rock Drilling and Sampling

Where borings must extend into weathered and unweathered rock formations, rock drilling and sampling procedures are required. The use of ISRM (International Society for Rock Mechanics) Commission on Standardization of Laboratory and Field Tests (1978, 1981) guidelines are recommended for detailed guidance for rock drilling, coring, sampling, and logging of boreholes in rock masses. This section provides an abbreviated discussion of rock drilling and sampling methods.

Defining the top of rock from drilling operations can be difficult, especially where large boulders exist, below irregular residual soil profiles, and in karst terrain. In all cases, the determination of the top of rock must be done with care, as an improper identification of the top of rock may lead to miscalculated rock excavation volume or erroneous pile length. As per ASTM D 2113, core drilling procedures are used when formations are encountered that are too hard to be sampled by soil sampling methods. A penetration of 25 mm (1 in) or less by a 51 mm (2 in) diameter split-barrel sampler following 50 blows using standard penetration energy or other criteria established by the geologist or engineer should indicate that soil sampling methods are not applicable and rock drilling or coring is required. In many instances, geophysical methods, such as seismic refraction, can be used to assist in evaluating the top of rock elevations in an expedient and economical manner. The refraction data can also provide information between confirmatory boring locations.